

(e) If the composition of the exhaust gas is influenced by any treatment such as heat exchanger or air injection (except catalysts and soot filters) then the exhaust probe must be taken upstream of this device.

**§ 89.414-96 Air flow measurement specifications.**

(a) The air flow measurement method used must have a range large enough to accurately measure the air flow over the engine operating range during the test. Overall measurement accuracy must be  $\pm 2$  percent of the reading for all modes except the idle mode. For the idle mode, the measurement accuracy shall be  $\pm 5$  percent or less of the reading. The Administrator must be advised of the method used prior to testing.

(b) When an engine system incorporates devices that affect the air flow measurement (such as air bleeds) that result in understated exhaust emission results, corrections to the exhaust emission results shall be made to account for such effects.

**§ 89.415-96 Fuel flow measurement specifications.**

The fuel flow rate measurement instrument must have a minimum accuracy of  $\pm 1$  percent of full-scale flow rate for each measurement range used. An exception is allowed at the idle point. For this mode (idle), the minimum accuracy is  $\pm 2$  percent of full-scale flow rate for the measurement range used. The controlling parameters are the elapsed time measurement of the event and the weight or volume measurement.

**§ 89.416-96 Raw exhaust gas flow.**

The exhaust gas flow shall be determined by one of the methods described

in this section and conform to the tolerances of Table 3 in appendix A to subpart D:

(a) Measurement of the air flow and the fuel flow by suitable metering systems (for details see SAE J244. This procedure has been incorporated by reference. See § 89.6.) and calculation of the exhaust gas flow as follows:

$$G_{EXHW} = G_{AIRW} + G_{FUEL} \quad (\text{for wet exhaust mass})$$

or

$$V_{EXHD} = V_{AIRD} + (-.767) \times G_{FUEL} \quad (\text{for dry exhaust volume})$$

or

$$V_{EXHW} = V_{AIRW} + .749 \times G_{FUEL} \quad (\text{for wet exhaust volume})$$

(b) Exhaust mass calculation from fuel consumption (see § 89.415-96) and exhaust gas concentrations using the method found in § 89.418-96.

**§ 89.417-96 Data evaluation for gaseous emissions.**

For the evaluation of the gaseous emission recording, the last 60 seconds of each mode are recorded, and the average values for HC, CO, CO<sub>2</sub>, and NO<sub>x</sub> during each mode are determined from the average concentration readings determined from the corresponding calibration data.

**§ 89.418-96 Raw emission sampling calculations.**

(a) The final test results shall be derived through the steps described in this section.

(b) The exhaust gas flow rate  $G_{EXHW}$  and  $V_{EXHW}$  shall be determined (see § 89.416-96) for each mode.

(c) When applying  $G_{EXHW}$  the measured concentration shall be converted to a wet basis according to the following formula, if not already measured on a wet basis.

$$K_w = \left[ 1 - F_{FH} \times \frac{G_{fuel}}{G_{air}} \right] - K_{w1} \quad \text{only applicable for raw exhaust}$$

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$F_{FH}$ =1.783 if air/fuel ratio is 1.00  
1.865 if air/fuel ratio is 1.35  
1.920 if air/fuel ratio is 3.50

(d) As the  $NO_x$  emission depends on ambient air conditions, the  $NO_x$  concentration shall be corrected for ambient air temperature and humidity with the factor  $K_H$  given in the following formulas. Equation (1) of this paragraph is to be used when testing in uncontrolled dynamometer rooms or at other sites with uncontrolled temperatures and humidities. Equation (2) of this paragraph is to be used for all testing when performed in controlled condition rooms. For engines operating on alternative combustion cycles, other correction formulas may be used if they can be justified or validated.

(1) For compression-ignition engines operating in uncontrolled conditions:

$$K_H = \frac{1}{1 + A(H - 10.71) + B(T - 298)}$$

Where:

$A=0.309 (f/a) - 0.0266$

$B=-0.209 (f/a)+0.00954$

$T$ =temperature of the air in K

$H$ =humidity of the inlet air in grams of water per kilogram of dry air in which:

$$H = \frac{6.220 \times R_a \times p_d}{(p_B - p_d) \times R_a \times 10^{-2}}$$

(2) For compression-ignition engines operating in controlled conditions:

$$K_H = \frac{1}{(1 - 0.0182(H - 10.71))}$$

If required the dry fuel/air ratio may be calculated from the following equation:  
Where:

$$(f/a) \text{ Stoich} = \frac{M_c + aM_H}{138.18(1 + a/4)}$$

$$X = \frac{DCO_2}{10^2} + \frac{DCO}{10^6} + \frac{DHC}{10^6}$$

$$K = 3.5$$

(e) The pollutant mass flow for each mode shall be calculated as follows:

$$\text{Gas mass} = u \times \text{Gas conc.} \times G_{EXHW}$$

$$\text{Gas mass} = v \times \text{Gas conc.} \times V_{EXHD}$$

$$\text{Gas mass} = w \times \text{Gas conc.} \times V_{EXHW}$$

The coefficients  $u$  (wet),  $v$  (dry), and  $w$  (wet) are to be used according to the following table:

Gas	$u$	$v$	$w$	Conc.
$NO_x$ .....	0.001587	0.00205	0.00205	ppm.
CO .....	0.000966	0.00125	0.00125	ppm.
HC .....	0.000478		0.000618	ppm.
$CO_2$ .....	15.19	19.64	19.64	percent.
$O_2$ .....	11.05	14.29	14.29	percent.

NOTE: The given coefficients  $u$ ,  $v$ , and  $w$  are calculated for 273.15 °K (0 °C) and 101.3 kPa. In cases where the reference conditions vary from those stated, an error may occur in the calculations.

(f) The following equations may be used to calculate the coefficients  $u$ ,  $v$ , and  $w$  in paragraph (e) of this section for other conditions of temperature and pressure.

(1) For ideal gases at 273.15 °K (0 °C) and 101.3 kPa:

For the calculation of  $u$ ,  $v$ , and  $w$  for  $NO_x$  (as  $NO_2$ ), CO, HC (in paragraph (e) of this section as  $H_{1.85}$ ;  $CO_2$ ;  $O_2$

$w=4.4615 \cdot 10^{-5} \cdot M$  if conc. in ppm

$w=4.4615 \cdot 10^{-1} \cdot M$  if conc. in percent

$v=w$

$u=w/P_{Air}$

$M$ =Molecular weight

$p_{Air}$ =Density of dry air at 273.15 °K (0 °C), 101.3 kPa=1.293 kg/m<sup>3</sup>

(2) For real gases at 273.15 °K (0 °C) and 101.3 kPa: For the calculation of  $u$ ,  $v$ , and  $w$

$w=\text{gas} \times 10^{-6}$  if conc. in ppm

$v=w$

$u = w/p_{Air}$

$p_{Gas}$  = Density of measured gas at 0 °C, 101.3 kPa in g/m<sup>3</sup>

(3) General formulas for the calculation of concentrations at temperature (designated as  $T$ ) and pressure (designated as  $p$ ):

—for ideal gases

$$\text{conc} \frac{\text{g}}{\text{m}_3} = \frac{M}{M_v} \times \frac{T_o}{T_o + T} \times \frac{P}{P_o} \frac{\text{Conc(ppm)}}{10^6}$$

—for real gases

$$\text{conc} \frac{\text{g}}{\text{m}_3} = \rho_{\text{Gas}} \times \frac{T_o}{T_o + T} \times \frac{P}{P_o} \frac{\text{Conc(ppm)}}{10^6}$$

with:

1% =  $10^4$  ppm

$M$  = Molecular weight in g/Mol

$M_v$  = Molecular Volume =  $22.414 \times 10^{-3}$  m<sup>3</sup>/Mol for ideal gases

$T_o$  = reference temperature 273.15 K

$p_o$  = reference pressure 101.3 kPa

$T$  = Temperature in °C

$p$  = pressure in kPa

$\rho_{\text{Gas}}$  = Density of the measured gas at 0 °C, 101.3 kPa

$\text{Conc.}$  = Gas concentration

(g) The emission shall be calculated for all individual components in the following way:

$$\text{individual gas} = \frac{\sum_{i=1}^{i=n} \text{Gas Mass}_i \times \text{WF}_i}{\sum_{i=1}^{i=n-1} P_i \times \text{WF}_i}$$

The weighting factors and the number of modes (n) used in the above calculation are according to § 89.410–96.

**§ 89.419–96 Dilute gaseous exhaust sampling and analytical system description.**

(a) *General.* The exhaust gas sampling system described in this section is designed to measure the true mass of gaseous emissions in the exhaust of petroleum-fueled nonroad compression-ignition engines. This system utilizes the CVS concept (described in § 86.1310–90 of this chapter) of measuring mass emissions of HC, CO, and CO<sub>2</sub>. A continuously integrated system is required for HC and NO<sub>x</sub> measurement and is allowed for all CO and CO<sub>2</sub> measurements. The mass of gaseous emissions is determined from the sample con-

centration and total flow over the test period. As an option, the measurement of total fuel mass consumed over a cycle may be substituted for the exhaust measurement of CO<sub>2</sub>. General requirements are as follows:

(1) This sampling system requires the use of a PDP-CVS and a heat exchanger or a CFV-CVS with either a heat exchanger or electronic flow compensation. Figure 2 in appendix A to this subpart is a schematic drawing of the PDP-CVS system. Figure 3 in appendix A to this subpart is a schematic drawing of the CFV-CVS system.

(2) The HC analytical system for petroleum-fueled compression-ignition engines requires a heated flame ionization detector (HFID) and heated sample system ( $191 \pm 11$  °C).

(i) The HFID sample must be taken directly from the diluted exhaust stream through a heated probe and integrated continuously over the test cycle. Unless compensation for varying flow is made, the HFID must be used with a constant flow system to ensure a representative sample.

(ii) The heated probe shall be located in the primary dilution tunnel and far enough downstream of the mixing chamber to ensure a uniform sample distribution across the CVS duct at the point of sampling.

(3) The CO and CO<sub>2</sub> analytical system requires:

(i) Bag sampling (see § 86.1309–90 of this chapter) and analytical capabilities (see § 86.1311–90 of this chapter), as shown in Figure 2 and Figure 3 in appendix A to this subpart; or

(ii) Continuously integrated measurement of diluted CO and CO<sub>2</sub> meeting